THE PARALLAX OF PULSAR 0950+08
AND THE LOCAL FREE ELECTRON DENSITY

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ABSTRACT

We report a parallax of 7.9±0.8 mas for PSR 0950+08, corresponding to a distance of 130±15 pc. The measured pulse dispersion of this pulsar implies an average free electron density of 0.023±0.002 cm^{-3} along the line of sight. This parallax measurement is subject to systematic errors and questions of interpretation which have not yet been fully explored.

INTRODUCTION

Annual parallaxes of nearby radio pulsars, in combination with their pulse dispersions, provide determinations of the local free electron density which are independent of other astrophysical models. The pulse dispersion is proportional to the dispersion measure, $DM=\int n_e dl$, where n_e is the free electron density and dl the line element along the line of sight (Manchester and Taylor 1977). The pulsar's parallax π is the inverse of its distance, so the average free electron density is along the line of sight is $\langle n_e\rangle=DM\cdot\pi$. PSR 0950+08 has the lowest dispersion measure of any known pulsar, so its parallax is of particular importance to studies of the local interstellar medium.

TECHNIQUES

Very Long Baseline Interferometry (VLBI) offers extremely high resolution at radio frequencies, allowing correspondingly precise measurements of radio source positions. In practice this precision is difficult to exploit, due to VLBI's sensitivity to minute variations in interferometer baseline length and orientation, and to changes in the radio signal's propagation medium. A particular difficulty in astrometric VLBI observations of pulsars is that pulsar spectra fall off steeply for frequencies f>100 MHz, while the ionosphere introduces a phase error which varies as f^{-2}, and which can change by an order of magnitude each day. With suitable ionospheric corrections, observations near 1.5 GHz represent the best compromise between these effects.

We observed at 1.66 GHz, measuring pulsar positions relative to nearby reference quasars with a phase-referencing technique similar to that used by Shapiro et al. (1979) for astrometric observations of quasars. We referenced the position of PSR 0950+08 to that of 0938+119, a quasar 4.8 degrees away. We recorded data with the Mark II VLBI system at radio telescopes at Arecibo, PR; Green Bank, WV; and Owens Valley, CA.

The tapes were cross-correlated to produce interference fringes at the Mark II processor in Charlottesville, VA. The cross-correlation functions were

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corrected for the effects of clock errors, precession and nutation, and the free motions of the earth. We also corrected for the ionosphere, the atmosphere, and the gravitational deflection of light by the sun. The ionospheric correction was made with data on the Faraday rotation of satellite signals, as observed at stations near the telescopes. The Faraday rotation data were related to ionospheric phase errors within a framework devised for correction of ionospheric effects on navigation satellite signals (Klobuchar 1975). The accuracy of this correction falls off rapidly with increasing separation, at ionospheric altitude, of the lines of sight from the telescope to the radio source and from the satellite antenna to the satellite. We observed at separations of up to 9 degrees in longitude. Comparisons of relative source positions as measured on different days indicate that our corrections reduce the systematic errors to an rms level of 0.03 turns of fringe phase per degree of program-reference source separation (Gwinn 1984). These comparisons are not complete due to lack of knowledge of the Mark II processor model.

Though enormously sensitive, the Arecibo telescope can observe only within 20 degrees of zenith. One can therefore obtain only a narrow range of orientations of interferometer baselines relative to a source, corresponding to a narrow range of interferometer fringe spacings on the sky. Information from our two more sensitive baselines, Arecibo-Green Bank and Arecibo-Owens Valley, yields a lattice of possible positions separated by integral numbers of turns of fringe phase. Additional assumptions are necessary to decide which combination of possible positions at each epoch represent the pulsar's motions between observations.

RESULTS

We have eight positions at four epochs for PSR 0950+08. To resolve fringe ambiguities, we took the pulsar's motion to agree as closely as possible with the proper motion as measured by Lyne, Anderson and Salter (1982). These positions yield, as a solution for parallax and proper motion,

$$\begin{array}{lll} \mu_\alpha = 17.9 \pm 3.0 & & \\ \mu_\delta = 35.8 \pm 4.0 & C(\mu_\alpha,\mu_\delta) = 0.79 & \\ \pi = 7.9 \pm 0.8 & C(\mu_\alpha,\pi) = -0.34 & C(\mu_\delta,\pi) = -0.11 \end{array}$$

where μ_α and μ_δ are the components of the pulsar's proper motion and π is its parallax. The C's are the normalized covariances, and the reduced chi-squared is 0.86. The proper motion agrees with Lyne, Anderson and Salter at the 1σ level. The solution differs from that reported by Taylor et al. (1984) only in the correction for the gravitational deflection of light by the sun. Deleting the positions from any one epoch leaves the parallax unchanged to within 0.8 mas, as does deleting positions from two epochs and solving for parallax with the proper motion fixed at the value of Lyne, Anderson and Salter. We searched for alternative solutions by shifting positions from each epoch by one or two fringe ambiguities. All solutions with a reduced chi-squared of 2.5 or less yielded a parallax within 0.8 mas of the above result; these solutions resulted from moving a single position by one fringe ambiguity, and are not fundamentally different. Significantly different solutions have greater reduced chi-squared and proper motions agreeing poorly with that of Lyne, Anderson and Salter.

CONCLUSIONS

PSR 0950+08's parallax of 7.9±0.8 mas corresponds to a distance of 130±15 pc. Its dispersion measure is 2.969 cm^{-3} pc, so we conclude that the average free electron density along the line of sight to this pulsar is 0.023±0.002 cm^{-3}.

This result is in good agreement with free electron densities measured along longer lines of sight by other techniques, which are consistent with an average free electron density of 0.03 cm^{-3} over kiloparsec scales (Weisberg, Rankin and Boriakoff 1984).

Previous attempts to measure pulsar parallax have used radio-linked interferometers, with much shorter baselines and about a factor of 30 lower resolution. Salter, Lyne and Anderson (1979) obtained nine results, only one of which was significantly nonzero: they obtained a parallax of 21.5±8.0 mas for PSR 1929+10, corresponding to an average free electron density of 0.069±0.026 cm^{-3} along the line of sight. They combined all nine of their results to find an average free electron density of 0.029±0.014 cm^{-3} in the solar neighborhood, in good agreement with our result for PSR 0950+08 above. Backer and Sramek (1982) reported an upper limit of 4 mas for the parallax of PSR 1929+10; this controversy has not yet been resolved.

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